Transfer Oscillator Technique for 10 GHz Generation with Ultra-Low Phase Noise < -100 dBc/Hz at 1 Hz offset

Nicholas V. Nardelli[1,2], Tara M. Fortier[1], Marco Pomponio[1,2], Esther Baumann[1,2], Craig Nelson[1], Thomas R. Schibli[2] and Archita Hati[1]

[1] National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA
[2] University of Colorado, Boulder, Colorado 80309, USA
Email: nicholas.nardelli@colorado.edu

Abstract: We generate 10 GHz microwave signals from an optical reference cavity using the transfer oscillator scheme with a free-running optical frequency comb. We demonstrate phase noise < -100 dBc/Hz at 1 Hz frequency offset from the carrier. © 2021 The Author(s)

Currently, the lowest noise microwave signals are generated via frequency division of high-stability optical references (OFD) [1-3] using femtosecond laser frequency combs (FLFCs). In contrast to OFD, which requires tight phase locking of the FLFC to an optical reference, the transfer oscillator (TO) technique [4] employs analog and direct digital synthesis to create a feedforward correction signal to cancel the FLFC noise from the generated microwave signal. As a result, the transfer oscillator technique generates environmentally robust and long-term microwaves even with a free-running FLFC. Additionally, the TO technique permits higher bandwidth suppression of FLFC noise than is possible via physical feedback actuators [5]. While OFD has demonstrated transfer of the fractional stability of an optical reference to the microwave domain enabling room-temperature generation of electronic signals with 10^{-15} instability, the best reported close-to-carrier noise generated using the TO oscillator technique has been -60 dBc/Hz at 1 Hz offset [5], limited by the measurement system noise floor. Here we use the TO technique to transfer the stability and phase noise of an optical reference at 1157 nm to 10 GHz and demonstrate an absolute close-to-carrier phase noise of -107 dBc/Hz, and a 1-second fractional frequency instability below 10^{-15}.

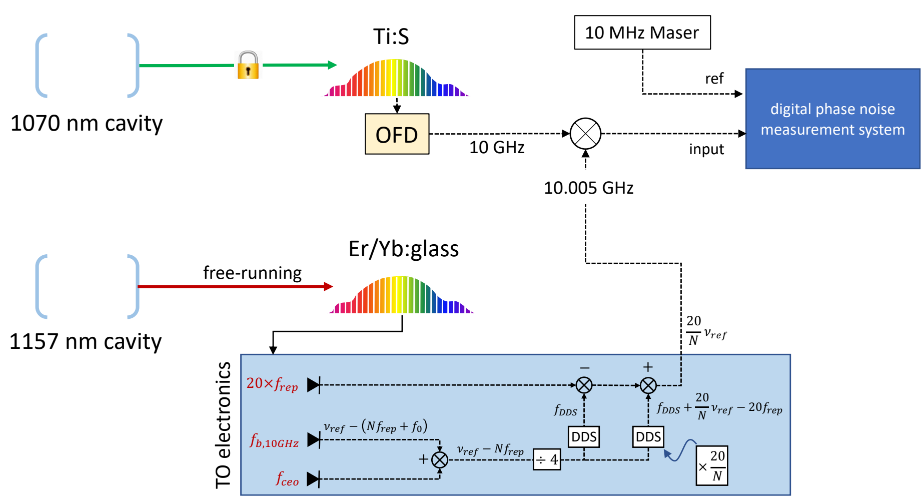

Fig. 1. Phase noise comparison between two optical frequency combs that are used to derive low-noise microwaves from high-stability optical cavities. The comb based on Ti:sapphire employs classical optical frequency division (OFD) based on tight stabilization of the comb to a 1070 nm ULE optical cavity, whereas the free-running Er/Yb:glass based comb employs the transfer oscillator (TO) technique.

In our measurements, we use a 500 MHz free-running optical frequency comb based on Er/Yb-doped glass to extract a 10 GHz signal from a 1157 nm optical reference cavity using the TO technique [4]. As seen in Figure 1, an optical beat between reference cavity light and a comb tooth (f_b) is detected and mixed with the offset frequency (f_{ceo}) to remove its noise contribution. This signal is then frequency divided and used to remove the comb noise from the 20th harmonic of the 500 MHz oscillator producing a high-stability 10 GHz signal.

*This work is a contribution of NIST, an agency of the US government, and is not subject to copyright in the U.S.

Authorized licensed use limited to: Boulder Labs Library. Downloaded on June 13,2022 at 13:54:24 UTC from IEEE Xplore. Restrictions apply.

To validate the TO technique, the TO output signal at 10.005 GHz is compared directly to the 10 GHz signal generated via classical OFD of a 1070 nm optical reference using a Ti:Sapphire (Ti:S) frequency comb [6] by creating a 5 MHz beat between them. This beat is analyzed with a digital phase noise measurement system. Figure 2 compares the 10 GHz signal coming directly from the free-running OFC to the 10 GHz signal after it is passed through the TO electronics. Also shown is the combined noise floor of the H-maser reference and measurement test set. As seen in Figure 2, the TO technique enables greater than 100 dB of noise suppression from the free running FLFC at 1 Hz offset from the carrier. The latter permits the extraction of 10 GHz signals with a phase noise below -100 dBc/Hz. While the close-to-carrier noise generated via the TO technique is comparable to that previously demonstrated via OFD, the high frequency noise floor is limited by quantization noise in the DDS at -150 dBc/Hz. An additional electronic noise source in the TO technique are IQ mixers that contribute -110 dBc/f noise close to the carrier.

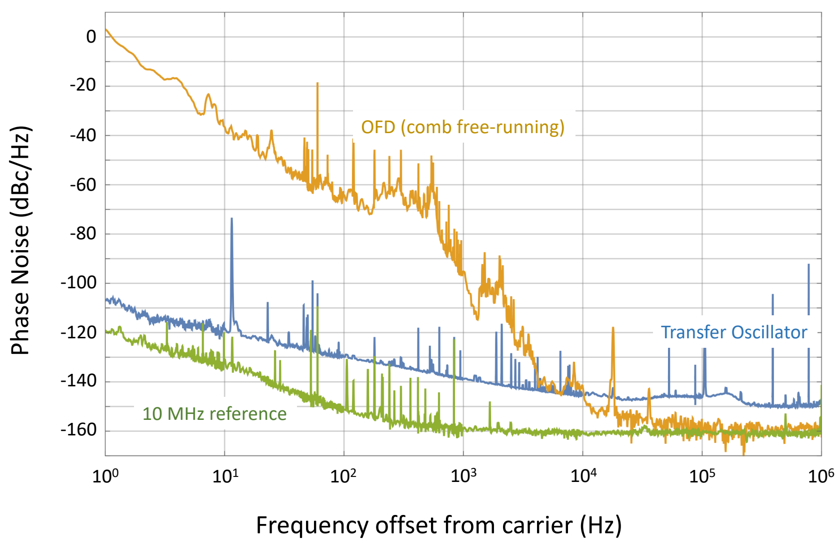

Fig. 2. Phase noise comparison of the extracted 10 GHz microwaves from the Er/Yb:glass laser as compared to a Ti:Sapphire based FLFC. The orange and blue traces shows the 10 GHz phase noise of the Er/Yb:glass laser obtained via OFD and the transfer oscillator technique, respectively. The blue trace demonstrates that the transfer oscillator technique can generate phase noise with close to carrier noise comparable to OFD and demonstrates > 100 dB of close-to-carrier noise suppression of the free running laser noise.

In conclusion, using the transfer oscillator technique, we demonstrate high-fidelity division of a high-stability reference to 10 GHz and generate close-to-carrier phase noise microwave signal comparable with that obtained via OFD. In the future, we plan to simultaneously generate 10 GHz signals from multiple optical references at different optical frequencies using the TO technique using a single FLFC. The latter experiment has natural application to microwave timescales derived from optical references.

References:

[1] T. M. Fortier, M. S. Kirchner, F. Quinlan, J. Taylor, J. C. Bergquist, T. Rosenband, N. Lemke, A. Ludlow, Y. Jiang, C. W. Oates, and S. A. Diddams, Nat. Photon. 5, 425 (2011).

[2] F. Quinlan, T. M. Fortier, M. S. Kirchner, J. A. Taylor, M. J. Thorpe, N. Lemke, A. D. Ludlow, Y. Jiang, C. W. Oates, and S. A. Diddams, "Ultralow phase noise microwave generation with an Er:fiber-based optical frequency divider," Opt. Lett. **36**, (2011).

[3] X. Xie, R.Bouchand, D. Nicolodi, M.Giunta, W. Hänsel, M. Lezius, A. Joshi, S. Datta, C. Alexandre, M. Lours, P. Tremblin, G. Santarelli, R. Holzwarth and Y. Coq, "Photonic microwave signals with zeptosecond level absolute timing noise," Nat. Photon. 11, 44-47, (2017).

[4] Telle, H., Lipphardt, B. & Stenger, J. Kerr-lens, mode-locked lasers as transfer oscillators for optical frequency measurements. Appl. Phys. B **74,** 1–6 (2002).

[5] P. Brochard, S. Schilt and T. Sudmeyer, "Ultra-low noise microwave generation with a free running optical frequency comb transfer oscillator," Opt. Lett. **43**, (2018).

[6] T. M. Fortier, A. Bartels and S. A. Diddams, "Octave-spanning Ti:sapphire laser with a repetition rate >1 GHz for optical frequency measurements and comparisons," *Opt. Lett.,* vol. 31, no. 7, p. 1011, 2006.

*This work is a contribution of NIST, an agency of the US government, and is not subject to copyright in the U.S.

Authorized licensed use limited to: Boulder Labs Library. Downloaded on June 13,2022 at 13:54:24 UTC from IEEE Xplore. Restrictions apply.